The impact of greenhouse gases and halogenated species on future solar UV radiation doses

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Abstract. The future development of stratospheric ozone layer depends on the concentration of chlorine and bromine containing species. The stratosphere is also expected to be affected by future enhanced concentrations of greenhouse gases. These result in a cooling of the winter polar stratosphere and to more stable polar vortices which leads to enhanced chemical depletion and reduced transport of ozone into high latitudes. One of the driving forces behind the interest in stratospheric ozone is the impact of ozone on solar UV-B radiation. In this study UV scenarios have been constructed based on ozone predictions from the chemistry-climate model runs carried out by GISS, UKMO and DLR. Since cloudiness, albedo and terrain height are also important factors, climatological values of these quantities are taken into account in the UV calculations. Relative to 1979-92 conditions, for the 2010-2020 time period the GISS model results indicate a springtime enhancement of erythemal UV doses of up to 90% in the 60-90 °N region and an enhancement of 100% in the 60-90 °S region. The corresponding maximum increases in the annual Northern Hemispheric UV doses are estimated to be 14 % in 2010-20, and 2 % in 2040-50. In the Southern Hemisphere 40 % enhancement is expected during 2010-20 and 27 % during 2040-50.

1. Introduction

The future impacts of halogenated species on stratospheric ozone have typically been studied using 2-dimensional (latitude-height) chemical transport models (CTMs). According to recent research it is essential to take into account the impact of changes in greenhouse gas concentrations on the dynamical behaviour of the Arctic and

Antarctic polar vortices [e.g. *Austin et al.*, 1992, 1994; *Shindell et al.*, 1998]. It may also be assumed that the use of 3-dimensional models may give a more realistic picture of the longitudinal distribution of ozone, especially in the Northern Hemisphere, where the polar vortex is typically smaller and more mobile. However, such models are highly computationally intensive and in recent studies three approaches have been used: 1) The climate and chemistry models have been run non-interactively [*Steil et al*, 1998], 2) The coupled model runs have been run for individual years separately rather than for several decades continuously [*Austin et al.*, 1999], 3) Climate model and simplified chemistry models have been run continuously for several decades [*Shindell, et al.*, 1998]. In this study results from all these approaches are compared.

2. Ozone Scenarios

In this study the impact of both climate change and stratospheric chemistry on surface UV levels are taken into consideration. For the calculations three model results for the future total ozone amounts have been compared: 1) The NASA GISS model (Global Climate/Middle Atmosphere model of Goddard Institute for Space Studies), 2) The UKMO model (UK Meteorological Office) and 3) The DLR model (DLR/MPI ECHAM3/CHEM model of the German Aerospace Establishment (DLR) Institute for Physics of the Atmosphere, the Max-Planck-Institute (MPI) for Chemistry, and the MPI for Meteorology).

In the GISS model [*Shindell et al.* 1997, 1998] the heterogeneous chlorine chemistry is parameterised as a function of temperature, and a contribution due to bromine is included by increasing the ozone destruction rates by 15% in all cases. In the GISS model the chemistry and the atmospheric circulation are coupled in that the radiative impact of ozone change is included. In this study a transient run for 1960-2070 is used, and 10-year averages for the 1990's, 2010's and 2040's form the basis for the UV scenarios.

Table 1. The concentrations of chlorine compounds and the greenhouse gases used in the climate-chemistry models. The DLR values of the concentrations for the 1990's represent year 1991, and for 2040's year 2050. The higher DLR Cly values represent Montreal protocol only, and the lower ones with its Copenhagen amendments. The 1979/80 and 1994/95 concentrations are based on atmospheric measurements, and the others are based on IPCC and Montreal protocol related estimates.

GAS/YEAR	1979/80	1994/95	1999/00	2004/05	2009/10	2014/15	2044/45
Cl_y, ppbv							
GISS	2.2	3.3	3.4	3.4	3.4	3.2	2.4
UKMO	2.0	3.1	3.2	3.2	3.0	2.9	2.2
DLR/MPI	2.3	3.2				2.7/4.9 *)	1.9/5.8 *)
CO_2, ppmv							
GISS	337	360	367	375	385	396	483
UKMO	333	361	371	382	393	405	490
DLR/MPI	337	353				413	513
CH_4, ppmv							
GISS	1.3	1.4	1.5	1.6	1.7	1.8	2.2
UKMO	1.6	1.7	1.8	1.9	1.9	2.0	2.6
DLR/MPI	1.6	1.7				2.0	2.5
N_2O, ppbv							
GISS	291	295	297	300	300	305	322
UKMO	297	311	316	320	325	330	362
DLR/MPI	303	310				330	360

*) The higher DLR/MPI Cl_y values represent Montreal protocol only, and the lower ones with its Copenhagen amendments.

The GCM and chemistry models are radiatively coupled to each other to take into account the impact of ozone variations on model temperatures and model winds on the transport of chemical species. The model was run for single annual cycles for the years 1979/80, 1994/95, 1999/00, 2004/05, 2009/10, 2014/15 and 2044/45.

The UKMO model [*Austin et al.* 1999] incorporates a comprehensive stratospheric chemistry scheme representing all the major ozone destruction processes, including explicit contributions from chlorine, bromine, nitrogen and hydrogen.

The DLR/MPI model has been run for time-slices by taking into account the gradual increase of the greenhouse gases in the atmosphere and additionally the increase of the NO_x-surface emissions. The results have been used non-interactively as data for a CTM including chlorine chemistry. Bromine chemistry is not included in the CTM. In this study 10-year averages of total ozone for 1980, 1991, 2015 and 2050 have been used. The model runs include estimates for Montreal protocol based chlorine scenarios only as well as for its Copenhagen amendments.

The concentrations of the halogenated and greenhouse gases are shown in Table 1 for the different models. The major difference is in the representation of Bromine, which is included in the UKMO model, in a simplified form in the GISS model and not at all in the DLR/MPI model.

3. Radiative Transfer Calculations

Clear sky irradiances are taken from lookup tables calculated by the well-tested and verified UVSPEC model [*Mayer et al.* 1997]. While earlier estimates of the impact of ozone depletion on solar UV radiation have been made for cloudfree atmospheres [e.g. *Slaper et al,* 1996], we account for clouds and nonabsorbing aerosols by using the TOMS reflectivity to modify the clear sky irradiances [*Eck et al.* 1995, *Herman et*

al. 1997, 1999]. In addition terrain height is accounted for. The cloud and surface information are from TOMS/Nimbus-7 1978-1993 monthly averages and are the same for all scenario calculations. The ozone column fields are monthly mean values adopted from TOMS/Nimbus-7 1978-1993 data or the various past, present and future ozone scenario calculations. While the inclusion of clouds and nonabsorbing aerosols gives the calculations more realism, the variation in the surface CIE doses between the different scenarios is caused by the variations in the ozone column. Similarly, sensitivity calculations have shown that the neglect of absorbing aerosols have no effect on the relative changes between the UV scenarios presented below.

4. UV Scenarios

The April (Northern Hemisphere) and October (Southern Hemisphere) monthly total UV doses for 1979-2050 polewards of 60 degrees are shown in Figure 1. The TOMS based climatology for 1979-92 is also shown. In general the three models lead to similar UV doses.

Both the UKMO and GISS results imply that their UV doses have their maxima well after the year 2000. This contrasts with typical 2-dimensional CTMs without GCM coupling which indicate maximum ozone depletion to take place around the year 2000 [e.g. *WMO,* 1998]. The 1979/80 UKMO based UV doses are somewhat higher than in the other two models' case. The difference between the hemispheres is also larger in the UKMO case. The DLR Montreal protocol run (Cl_y = 4.9 ppbv) is comparable with the GISS results, whereas the DLR Copenhagen run (Cl_y = 2.7 ppbv) shows significantly slightly lower UV doses in 2010-20.

The differences between the model results are probably largely due to the formulation of the chemistry. In the GISS model, depletion occurs locally according to the temperature

distribution and depleted ozone is not advected to other regions. The UKMO model and DLR/MPI are more similar in formulation and the higher UV indicated for the UKMO results, particularly in the Northern Hemisphere, may be largely due to the absence of Bromine in the DLR/MPI simulations. Apart from these generalisations there are still differences in the model results, which stem from the underlying model dynamics.

The results for the GISS model are shown as an example of geographical distribution of UV changes. This model was chosen because the simulated UV trend changes are largest among the models and also in order to give further analysis of the large ozone depletion scenarios reported by *Shindell et al.* [1998]. Comparison of the GISS model results relative to the 1979-92 climatology is shown in Figures 2 and 3. The comparison has been made for spring months (April for Northern, and October for Southern Hemisphere) and for annual UV doses. The maximum springtime changes in the Southern Hemisphere exceed 100 %, whereas in the Northern Hemisphere 90 % is reached in Greenland. In the Northern Hemisphere the changes are expected to be largest over the European sector of the Arctic. In the 2040-50 time period UV changes exceeding 50 and 20 % are seen in the SH and the NH, respectively.

5. Summary and Conclusions

It is evident that the erythemal solar UV radiation doses may be considerably enhanced due the ozone changes caused by the increase in the concentrations of greenhouse gases and halogenated species. It is possible that the enhanced UV doses may exist until at least the middle of the 21st century, particularly in the high latitude Northern and Southern
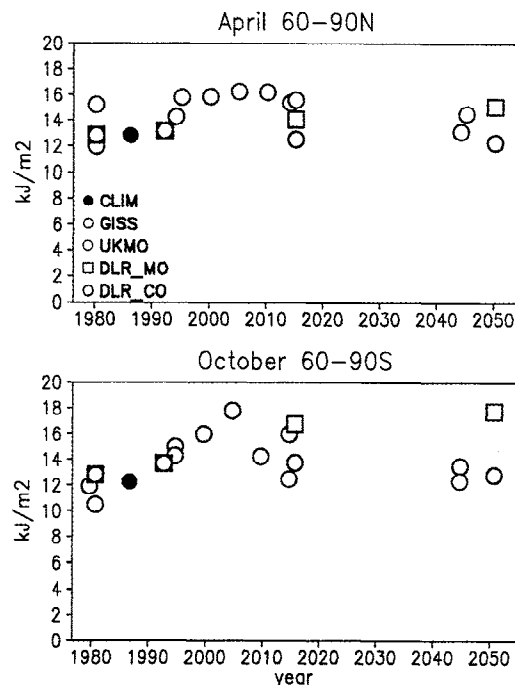

Figure 1. The monthly mean CIE weighted springtime UV doses for 60-90 °N (upper panel) and for 60-90 °S. The calculations are based on ozone scenario runs of GISS, UKMO and DLR/MPI. The DLR/MPI runs are made for Montreal Protocol based CFC emissions (DLR_MO) as well as for its Copenhagen amendments (DLR_CO). The CLIM represents TOMS 1979-92 climatology. Cloudiness, albedo and surface heights have been taken into account while calculating the UV doses. The DLR/MPI and GISS values represent 10-year averages, whereas the UKMO values are calculated for single years.
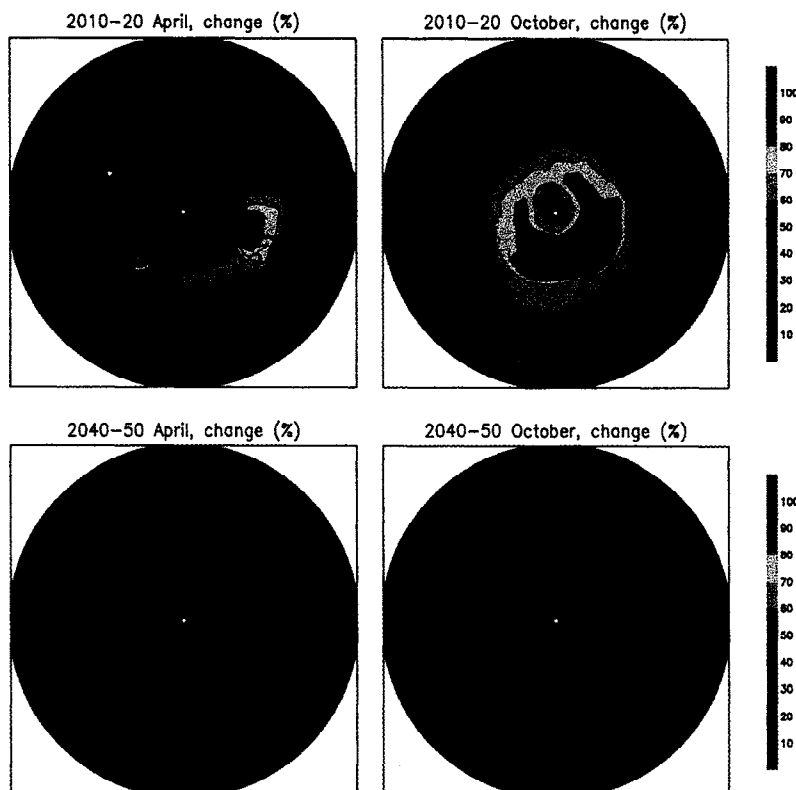

Figure 2. The relative differences between 1979-92 climatological average CIE-weighted UV doses and the UV scenarios derived from the GISS derived ozone for 2010-20 and 2040-50. The Northern Hemisphere values represent April means, and the Southern Hemisphere October means.
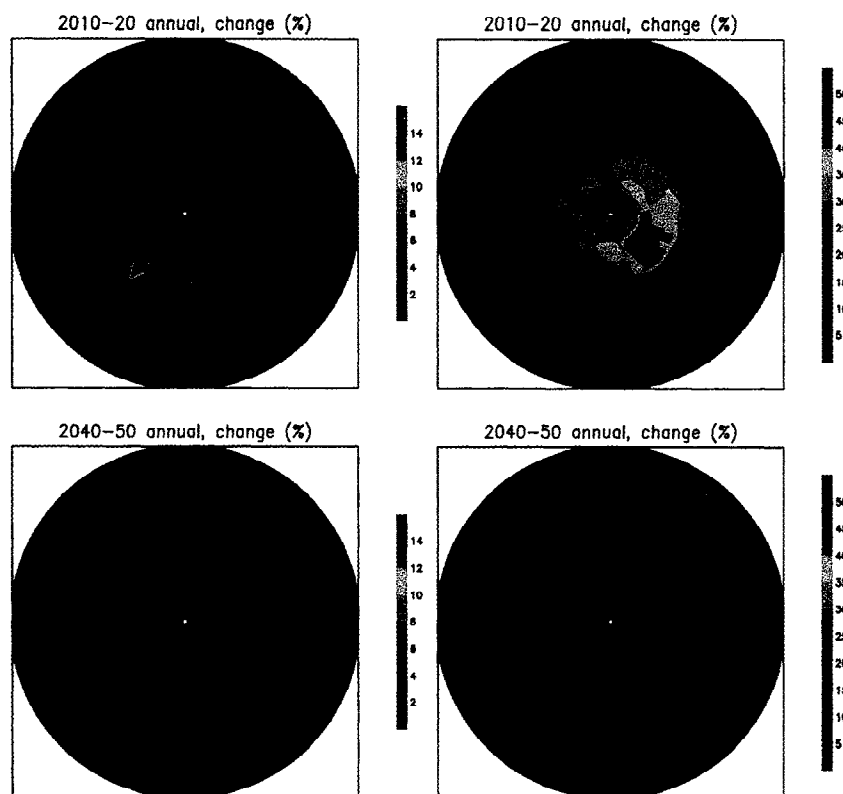
Figure 3. The relative differences between 1979-92 average CIE-weighted UV doses and the UV scenarios derived from the GISS derived 10-year average ozone for 2010-20 and 2040-50. Annual averages have been compared. Note the different scales for the two hemispheres.

Hemispheres. In the Northern Hemisphere the largest UV changes are expected to occur in the European sector of the Arctic. This may potentially have impacts on the Barents Sea ecosystem, which is a very important fishing area.

It is expected that further availability of powerful supercomputers will allow more extensive studies with comprehensive coupled GCM-CTMs to be performed. Also it would be important to be able to estimate future changes in cloudiness, albedo and aerosols with better consistency to be able to include those potentially important changes in the UV scenario estimates.

References

Austin, J., Butchart, N. & Shine, K. P., Possibility of an Arctic ozone hole in a doubled-CO_2 climate, *Nature 360*, 221-225, 1992.

Austin, J. & Butchart, N., The influence of climate change and the timing of stratospheric warmings on Arctic ozone depletion, *J. Geophys. Res. 99*, 1127-1145, 1994.

Austin, N. Butchart and J. Knight, Three-dimensional chemical model simulations of the ozone layer: 1979-2015, submitted to *QJRMS*, 1999.

Dameris, M., V. Grewe, R. Hein, C. Schnadt, C. Bruhl and B. Steil, Assessment of the future development of the ozone layer, *Geophys. Res. Lett. 25*, 3579-3582, 1998.

Eck, T. F., P. K. Bhartia & J. B. Kerr, Satellite estimation of spectral UVB irradiance using TOMS derived total ozone and UV reflectivity, *Geophys. Res. Let. 22*, 611-614, 1995.

Herman J. R. & Celalier, E. A., Earth surface reflectivity climatology at 340 nm to 380 nm from TOMS data, *J. Geophys. Res. 102*, 28003-28011, 1997.

Herman J. R., Celalier, E. A. & D. Larko, UV 380 nm reflectivity of Earth's surface. *J. Geophys. Res.*, in print, 1999.

Mayer, B., G. Seckmeyer & A. Kylling, Systematic long-term comparison of spectral UV measurements and UVSPEC modelling results, *J. Geophys. Res. 102*, 8755-8767, 1997.

Shindell, D. T., Wong, S. & Rind, D., Interannual variability of the Antarctic ozone hole in a GCM: Part I. The influence of tropospheric wave variability, *J. Atmos. Sci. 54*, 2308-2319, 1997.

Shindell, D. T., Rind, D. J. & Lonergan, P., Increased polar stratospheric ozone losses and delayed eventual recovery due to increasing greenhouse gas concentrations, *Nature 392*, 589-592, 1998.

Slaper H., Velders, G. J. M., Daniel, J. S., de Gruijl, F. R. and J. C. van der Leun, Estimates of ozone depletion and skin cancer incidence to examine the Vienna Convention achievements, *Nature 384*, 256-258, 1996.

Steil, B., Dameris, M. Bruehl, C. Crutzen, P. J. Grewe, V. Ponater, M. & Sausen, R., Development of a chemistry module for GCMs: First results of a multi-annual integration, *Ann. Geophysicae, 16*, 205-228, 1998.

WMO, Scientific Assessment of Ozone Depletion: 1998, *WMO Global Ozone Research and Monitoring Project - Report No. 44*, Geneva, 1998.

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